# Suomi National Polar-orbiting Partnership
# Visible Infrared Imaging Radiometer Suite
# S-NPP/VIIRS

## 375 m Active Fire Detection Algorithm

## User's Guide

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# 1. Introduction

This document describes the Suomi-National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (S-NPP/VIIRS) active fire detection product based on that instrument's 375 m nominal resolution data. Compared to other coarser resolution (≥1 km) satellite fire detection products, the improved 375 m data provide greater response over fires of relatively small areas, as well as improved mapping of large fire perimeters. Consequently, the data are well suited for use in support of fire management (e.g., near real-time alert systems), as well as other science applications requiring improved fire mapping fidelity. The 375 m product complements the baseline S-NPP/VIIRS 750 m active fire detection and characterization data, which was originally designed to provide continuity to the existing 1 km Earth Observing System Moderate Resolution Imaging Spectroradiometer (EOS/MODIS) active fire data record. Due to frequent data saturation issues, the current 375 m fire product provides detection information only with no sub-pixel fire characterization.

# 2. Science Background

The S-NPP/VIIRS 375 m active fire detection data build on the EOS/MODIS fire product heritage [Kaufman *et al*., 1998; Giglio *et al*., 2003], using a multi-spectral contextual algorithm to identify sub-pixel fire activity and other thermal anomalies in the Level 1 (swath) input data. The algorithm uses all five 375 m VIIRS channels to detect fires and separate land, water, and cloud pixels in the image. Additional 750 m channels complement the available VIIRS multispectral data. Those channels are used as input to the baseline active fire detection product, which provides continuity to the EOS/MODIS 1 km *Fire and Thermal Anomalies* product.

The 375 m data describe the nominal resolution after native data are spatially aggregated (Figure 1). The aggregation scheme changes across three distinct image regions. In the first region (nadir to 31.59$^o$ scan angle), three native pixels are aggregated in the along scan (cross-track) direction to form one data sample in the Level 1 image. In the second region (31.59$^o$ to 44.68$^o$ scan angle), two native pixels are aggregated to form one data sample. Finally in the third and last region (44.68$^o$ to 56.06$^o$ - edge of swath) one native pixel will result in one data sample. All five 375 m channels are aggregated onboard the spacecraft before the data are transmitted to the ground stations, whereas a subset of the VIIRS 750 m data (dual-gain channels only) are aggregated on the ground.

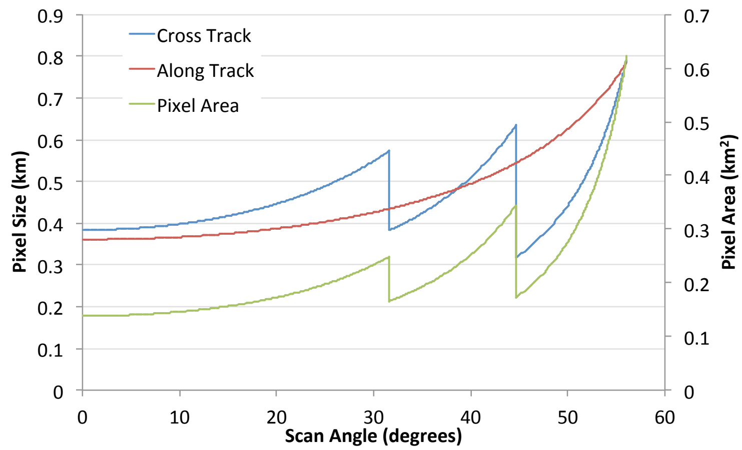


**Figure 1**: Spatial resolution of VIIRS imager data as a function of scan angle. The three distinct regions represent unique data aggregation zones extending across the swath.

Given the unique spatial and spectral resolution of the data, the VIIRS 375 m fire detection algorithm was customized and tuned in order to optimize its response over small fires while balancing the occurrence of false alarms. Similarly, frequent saturation of the mid-infrared channel (3.55-3.93 μm) driving the detection of active fires requires additional tests and procedures to avoid pixel classification errors. As a result, sub-pixel fire characterization (e.g., fire radiative power [FRP] retrieval) is only viable across small and/or low-intensity fires. Systematic FRP retrievals should be included in a future release of the algorithm based on a hybrid approach combining 375 and 750 m data. In fact, starting in 2015 the algorithm incorporated additional VIIRS channel M13 (3.973-4.128 μm) 750 m data in both aggregated and unaggregated format. The move was meant to improve handling of spurious fire pixel detection associated with the South Atlantic Magnetic Anomaly (see Table 1 and Section 3).

**Table 1**: List of VIIRS channel data used as input to the 375 m active fire detection algorithm. The terrain-corrected geolocation data (GITCO) complements the input files used by the fire algorithm.

| Channel | Range (μm) | Use |
|---|---|---|
| **I1** | 0.60 – 0.68 | Cloud & water classification |
| **I2** | 0.846 – 0.885 | Cloud & water classification |
| **I3** | 1.58 – 1.64 | Water classification |
| **I4** | 3.55 – 3.93 | Fire detection |
| **I5** | 10.5 – 12.4 | Fire detection & cloud classification |
| **M13*** | 3.973 – 4.128 | Flagging of low confidence nighttime fire pixels associated with the South Atlantic Magnetic Anomaly |

* Aggregated (750×750 m nominal) & unaggregated (250×750 m nominal) data are used

To date, the algorithm has been implemented regionally and globally using either direct readout (regional receiving stations) or regular science data available through NASA and NOAA data processing streams and archives. Data verification and validation was performed for selected sites across the globe, including dedicated field campaigns exploring small-to-medium size (<500 ha) prescribed fires. Product performance metrics can be found in Schroeder *et al*. [2014].

Currently, processing of the 375 m fire algorithm is limited to the Level 2 (swath) product output, which is designed using a data structure and format similar to MODIS Level 2 (MOD14/MYD14) fire product. It includes two-dimensional fire mask and quality assurance science data sets, plus sparse arrays describing individual fire pixel information and additional granule attributes. Alternative text (ASCII) files are generated for each Level 2 granule containing basic fire detection information in a Geographic Information System (GIS)-friendly format. Provisions for Level 3 (gridded) and 4 (Climate Modeling Grid) product outputs may be added in the future.

# 3. Product Description

The VIIRS 375 m fire detection data is a Level 2 product based on the input Science Data Record (SDR) Level 1 swath format. The product is currently available through NASA's Direct Readout Laboratory International Polar Orbiter Processing Package (IPOPP), the Land Science Investigator Processing System (SIPS), and the Land, Atmosphere Near real-time Capability for EOS (LANCE). The standard output data are stored as HDF4 files. Complementary ASCII files containing the short list of fire pixels detected are also available through IPOPP and LANCE processing systems.

A single file (granule) comprises an orbit segment spanning multiple scans, with each individual cross-track scan describing 32 rows of pixels (Y axis), one row for each detector. Each scan row contains a total of 6400 samples (X axis) consisting of 375 m nominal resolution (aggregated) pixels. The number of scans stored in a single file may vary depending on the characteristics of the input data and processing system, whereas multiples of 48 are used. As a result, the minimum array size of the fire mask will have $n$=1×48 scans, or 6400×1536 elements corresponding to an ≈85 second orbit segment.

## 3.1. Science Data Sets

The image classification product (fire mask) is the primary output science data set consisting of a two dimensional array with same [x, y] dimension as the input VIIRS 375 m SDR data used by the fire algorithm (Figure 2).

The fire mask contains 10 different pixel classes that build on the heritage EOS/MODIS active fire product. Three of those classes are used to flag fire-affected pixels along with their detection confidence (Table 1). Contrary to the EOS/MODIS fire detection data, the confidence parameter available for individual VIIRS 375 m pixels provide qualitative information only.

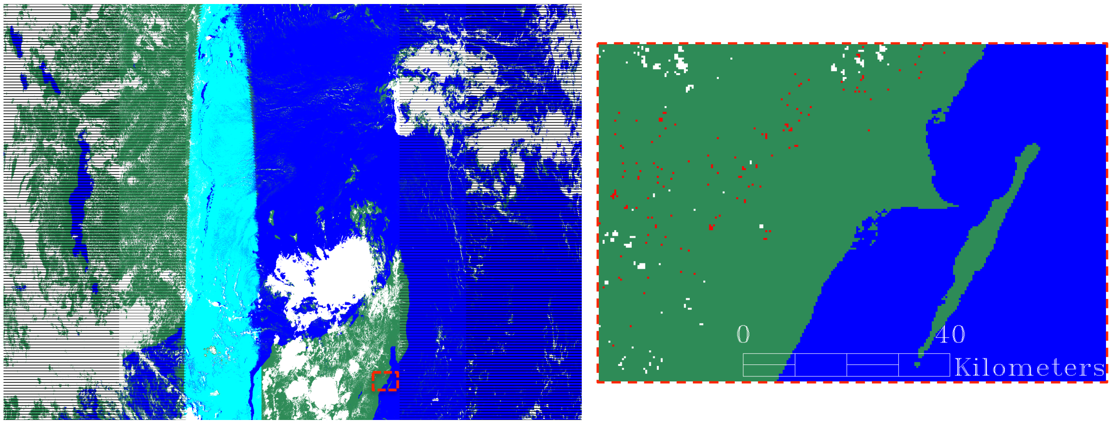


**Figure 2**: S-NPP/VIIRS 375 m active fire detection classification product (mask) derived for 5-min granule acquired on 22 November 2015 at 1035UTC over parts of northern Madagascar and southeast Africa (left). Right panel shows magnified subset containing land (green), water (blue), clouds (white) and fire (red) pixels. Glint (cyan) and bow-tie deletion (black) pixels are also visible in the large image.

**Table 1**: VIIRS 375 m 'fire mask' data set classes.

| Pixel Class | Definition |
|---|---|
| **0** | Not processed |
| **1** | Bow-tie deletion |
| **2** | Glint region |
| **3** | Water |
| **4** | Clouds |
| **5** | Land |
| **6** | Unclassified |
| **7** | Low confidence fire pixel |
| **8** | Nominal confidence fire pixel |
| **9** | High confidence fire pixel |

Low confidence daytime fire pixels are typically associated with areas of sun glint and lower relative temperature anomaly (<15K) in the mid-infrared channel I4. Meanwhile, low confidence nighttime pixels occur only over the geographic area extending from 11°E to 110°W and 7°N to 55°S. This area describes the region of influence of the South Atlantic Magnetic Anomaly, which can cause spurious brightness temperatures in the mid-infrared channel I4 leading to potential false alarms (Figure 3). *Unless users have a high false alarm tolerance, we recommend discarding nighttime low confidence fire pixels altogether*. Nominal confidence pixels are those pixels free of potential sun glint contamination during the day, and marked by strong (>15K) temperature anomaly in either day or nighttime data. Finally, high confidence fire pixels are associated with day or nighttime saturated pixels, including nominal saturation and digital number (DN) folding (i.e., pixels that greatly exceed the saturation temperature causing the DN value to fold over).

Pixels not processed represent image elements with missing or non-nominal quality data in one or more of the input data sets. *Bow-tie deletion* pixels correspond to redundant data elements in the image that are deleted prior to relay to the ground stations in order to reduce downlink bandwidth [Wolfe *et al*., 2013]. The *glint region* identifies pixels in the scene subject to high solar reflectance caused by favorable sun-surface-satellite geometry. Unclassified pixels coincide with those cases when the analysis of individual pixels was prevented due to insufficient background information. Complementary land, water and cloud pixels are classified using internal tests included in the algorithm (see Schroeder *et al*. [2014] for details).

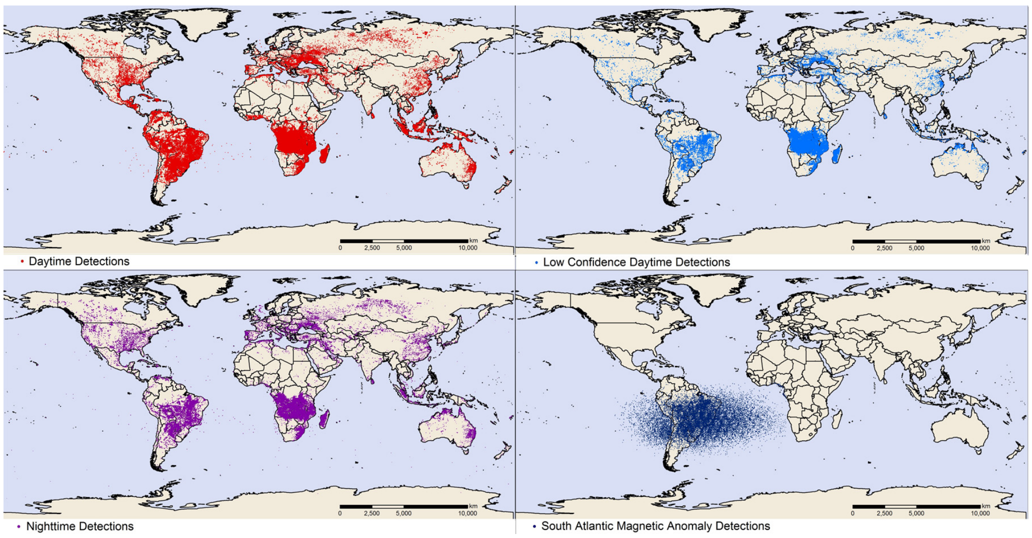


**Figure 3**: VIIRS 375 m global fire detection data generated for the period of 1-30 August 2013. Top panels show nominal/high (left) and low (right) confidence daytime detections. Bottom panels show nighttime detections of nominal/high confidence (left), and low confidence (right) overlapping the area of influence of the South Atlantic Magnetic Anomaly (adapted from Schroeder *et al*. [2014]).

A companion science data set is available providing quality assurance information for every pixel in the image. Quality assurance data are stored in 32-bit format detailing a variety of observation conditions that, when used in combination with the fire mask, can help explain specific pixel analysis outcomes (Table 2).

**Table 2**: VIIRS 375 m fire detection quality assurance bits and definition. Detection tests are derived from Schroeder *et al*. [2014].

| Bit | Description |
|---|---|
| **0** | Channel I1 quality (0 = nominal (or nighttime), 1 = non-nominal) |
| **1** | Channel I2 quality (0 = nominal (or nighttime), 1 = non-nominal) |
| **2** | Channel I3 quality (0 = nominal (or nighttime), 1 = non-nominal) |
| **3** | Channel I4 quality (0 = nominal, 1 = non-nominal) |
| **4** | Channel I5 quality (0 = nominal, 1 = non-nominal) |
| **5** | Geolocation data quality (0 = nominal, 1 = non-nominal) |
| **6** | Channel M13 quality (0 = nominal, 1 = non-nominal) |
| **7** | Unambiguous fire (0 = no, 1 = yes [night only]) |
| **8** | Candidate pixel (0 = no, 1 = yes)<br>T4 > 325 K AND T4-T5 > 25 K (daytime)<br>T4 ≥ 295 K AND T4-T5 > 10 K (nighttime) |

| | |
|---|---|
| **9** | Background pixel (0 = no, 1 = yes)<br>T4 > 335 K AND T4-T5 > 30 OR Saturated T4 (day)<br>T4 > 300 K AND T4-T5 > 10 OR Saturated T4 (night) |
| **10** | Bright pixel rejection (0 = no, 1 = yes)<br>R3 > 30% AND R3 > R2 AND R2 > 25% AND T4 ≤ 335K |
| **11** | Scene background (0 = no, 1 = yes)<br>T4 > MIN([330, scene_background]) |
| **12** | Test 1 (0 = no, 1 = yes)<br>T4-T5 > Mean(T4-T5)+2*AbsDev(T4-T5) (day)<br>T4-T5 > Mean(T4-T5)+3*AbsDev(T4-T5) (night) |
| **13** | Test 2 (0 = no, 1 = yes)<br>T4-T5 > Mean(T4-T5)+10 (day)<br>T4-T5 > Mean(T4-T5)+9 (night) |
| **14** | Test 3 (0 = no, 1 = yes)<br>T4 > Mean(T4)+3.5*AbsDev(T4) (day)<br>T4 > Mean(T4)+3*AbsDev(T4) (night) |
| **15** | Test 4 (0 = no, 1 = yes)<br>T5 > Mean(T5)+AbsDev(T5)-4 OR AbsDev(T4) > 5 |
| **16** | Pixel saturation condition (0 = no, 1 = yes)<br>T5 ≥ 325 OR T4 = 367 |
| **17** | Glint condition (0 = no, 1 = yes)<br>(T4-T5 ≤30 OR Glint LT 15°) AND fire pixel |
| **18-31** | Reserved for future use |

Additional data sets such as fire pixel line [y] and sample [x], latitude and longitude, and corresponding brightness temperatures are stored in vector format, each containing *N* records representing the number of fire pixels detected (Table 3). In order to avoid ambiguity, cases of DN folding are addressed during processing and channel I4 brightness temperatures assigned the nominal saturation value of 367 K. An FRP data set containing fill values was also added to the output HDF files in order to make it consistent with MODIS fire detection data. Future release of the VIIRS 375 m may include non-fill FRP values retrieved using complementary unsaturated M13 channel 750 m data.

**Table 3**: Complementary VIIRS 375 m fire detection science data sets. Individual data sets contain *N* entries corresponding to *N* fire pixels detected.

| Data set | Description | Units | Type |
|---|---|---|---|
| **FP_line** | Fire pixel line | - | uint16 |
| **FP_sample** | Fire pixel sample | - | uint16 |
| **FP_latitude** | Fire pixel latitude | Degrees | float32 |
| **FP_longitude** | Fire pixel longitude | Degrees | float32 |
| **FP_T4** | Fire pixel channel I4 brightness temperature | Kelvin | float32 |
| **FP_T5** | Fire pixel channel I5 brightness temperature | Kelvin | float32 |
| **FP_MeanT4** | Background channel I4 brightness temperature | Kelvin | float32 |
| **FP_MeanT5** | Background channel I5 brightness temperature | Kelvin | float32 |
| **FP_MeanDT** | Background channel I4-I5 brightness temperature difference | Kelvin | float32 |
| **FP_MAD_T4** | Mean absolute deviation (channel I4 background) | Kelvin | float32 |

| | | | |
|---|---|---|---|
| **FP_MAD_T5** | Mean absolute deviation (channel I5 background) | Kelvin | float32 |
| **FP_MAD_DT** | Mean absolute deviation (background channel I4-I5 temperature difference) | Kelvin | float32 |
| **FP_power** | Fire radiative power (fill value = 0) | Watts | float32 |
| **FP_AdjCloud** | Number of adjacent cloud pixels | - | uint16 |
| **FP_AdjWater** | Number of adjacent water pixels | - | uint16 |
| **FP_Winsize** | Window size (contextual analysis) | - | uint16 |
| **FP_confidence** | Fire detection confidence (7=low, 8=nominal, 9 = high) | - | byte8 |
| **FP_day** | Day/night flag | - | Byte8 |
| **FP_SolZenAng** | Fire pixel solar zenith angle | Degrees | float32 |
| **FP_SolAzAng** | Fire pixel solar azimuth angle | Degrees | float32 |
| **FP_ViewZenAng** | Fire pixel view zenith angle | Degrees | float32 |
| **FP_ViewAzAng** | Fire pixel view azimuth angle | Degrees | float32 |

### 3.2. Granule Attributes

Several global attributes are included in the output HDF file providing comprehensive information about individual granules. Those attributes describe summary statistics detailing the number of fire, land, and water pixels, day/night flag, and the granule's beginning/ending times and bounding geographic coordinates, among others. Information about granule attributes can be accessed using HDF-enabled software (see Section 4).

## 4. Data Handling

The output VIIRS 375 m active fire detection ASCII data can be handled using standard text editors and other software capable of ingesting comma-separated tabular data (e.g., ESRI ArcGIS, Microsoft Excel).

The HDF output is available in the satellite (swath) projection. A data reprojection tool can be downloaded from the VIIRS Land Science portal at: http://viirsland.gsfc.nasa.gov/Tools.html. The swath-to-grid tool allows users to convert the fire mask swath data into standard geo-referenced output files (e.g., GeoTIFF).

The HDF data can be opened/handled using commercial off the shelf as well as publicly available software (e.g., ENVI/IDL, HDFView). The example below describes a short IDL code that can be used to read the 'fire mask', 'FP_latitude', and 'FP_longitude' science data sets present in the HDF files.

```
PRO read_vnp14img,input_file

  ;input_file = input VNP14IMG*.hdf file (including full path)

  ;Open input HDF file for reading
  sd_id = HDF_SD_START(input_file,/READ)

  ;Read fire mask data set (2-dimensional array)
  sds_index = HDF_SD_NAMETOINDEX(sd_id,'fire mask')
  sds_id = HDF_SD_SELECT(sd_id,sds_index)
  HDF_SD_GETDATA,sds_id,mask
  HDF_SD_ENDACCESS,sds_id

  ;Read global attribute FirePix
  att_id = HDF_SD_ATTRFIND(sd_id,'FirePix')
  HDF_SD_ATTRINFO,sd_id,att_id,DATA=firepix

  ;Read fire pixel coordinates (if applicable)
  IF (firepix GT 0) THEN BEGIN
    ;Read fire pixel latitude data set (vector)
    sds_index = HDF_SD_NAMETOINDEX(sd_id,'FP_latitude')
    sds_id = HDF_SD_SELECT(sd_id,sds_index)
    HDF_SD_GETDATA,sds_id,fp_lat
    HDF_SD_ENDACCESS,sds_id
    ;Read fire pixel longitude data set (vector)
    sds_index = HDF_SD_NAMETOINDEX(sd_id,'FP_longitude')
    sds_id = HDF_SD_SELECT(sd_id,sds_index)
    HDF_SD_GETDATA,sds_id,fp_lon
    HDF_SD_ENDACCESS,sds_id
  ENDIF

  ;Close HDF file
  HDF_SD_END,sd_id

END
```

## 5. Complementary VIIRS 750 m Active Fire Data

Complementary VIIRS 750 m active data are available through NASA's Land SIPS (product name: NPP_VAFIRE_L2D, archive: 3001), and NOAA Interface Data Processing Segment (IDPS; product name: AVAFO) and NPOESS Data Exploitation (NDE). With the exception of the IDPS fire data product, which builds on the EOS/MODIS Collection 4 active fire detection algorithm and provides data vectors containing fire pixel latitude and longitude only, the other two variants above build on the latest EOS/MODIS Collection 6 active fire detection algorithm. Those data products include HDF file outputs of similar format/content as the heritage EOS/MODIS time series. Users are referred to NASA's Level 1 and Atmosphere Archive and Distribution System (LAADS Web) data portal for access to S-NPP/VIIRS 750 m active fire data: https://ladsweb.nascom.nasa.gov/. A link to

NOAA's operational VIIRS 750 m fire data shall be made available in a future version of this document once the NDE data output are released to the public.

## 6. Frequently Asked Questions

Q: *What is the temporal frequency of the VIIRS 375 m fire data*?
A: The 3,040 km VIIRS swath enables ≈15% image overlap between consecutive orbits at the equator, thereby providing full global coverage every 12h. The nominal (equator-crossing) overpass times are 1:30pm and 1:30am. Thanks to its polar orbit, mid-latitudes will experience 3-4 looks a day.

Q: *What is the main difference between the VIIRS 375 m and 750 m active fire data*?
A: The two data products use similar methodologies to detect active fire pixels although differences in the spectral characteristics of the VIIRS channels used in each case led to unique algorithms. Because of its improved spatial resolution, the 375 m algorithm will tend to detect more fire pixels compared to the 750 m data set. That difference is particularly pronounced during the nighttime part of the orbit when the occurrence of smaller/cooler fires will favor the 375 m product.

Q: *Will the VIIRS 375 m fire detection algorithm always outperform the 750 m one*?
A: Generally speaking, the higher resolution product will achieve higher probability of fire detection in both day and nighttime scenes. However, areas subject to strong solar reflectance associated with sun glint could see a few 750 m fire pixels without a corresponding 375 m fire detection. This is attributed to the relatively shorter wavelength of the 375 m mid-infrared channel used in the fire algorithm, which will experience greater influence of the solar component. In order to minimize the associated consequences, namely the occurrence of false alarms over bright/reflective surfaces (e.g., metallic factory rooftops), the 375 m algorithm uses slightly more conservative tests to avoid the effects of sun glint over those areas.

Q: *How often do fire pixels saturate the 375 m mid-infrared channel*?
A: Quite often. There are three main scenarios associated with saturated pixels in the I4 mid-infrared channel used in the fire detection algorithm. First there is the typical saturation condition in which the pixel is assigned the nominal saturation temperature of 367 K. The second scenario involves the more extreme case when the fire signal will greatly exceed the resolvable brightness temperature in channel I4. In that case, the pixel's digital number will fold over and show an abnormally low temperature which can be confronted by the companion long-wave infrared channel (I5) data. The third and last scenario is the more challenging one. It represents those cases when native pixels that reach saturation are mixed with other non-saturated pixels during data aggregation resulting in corrupted Level 1 radiances. Currently, there are no quality flags available in the input Level 1 SDR indicating those anomalies. The different saturation scenarios above are believed to have small/negligible effect on the fire detection performance. However, their occurrence is a major factor limiting the retrieval of sub-pixel fire characteristics (FRP).

Q: *Are the VIIRS 375 m (and 750 m) active fire data science-ready*?
A: The VIIRS active fire data have been extensively tested since routine production of the mission's data record started in 19 January 2012. Numerous bad scan episodes (i.e., pixel clusters containing spurious radiances extending across the swath) were found in the Level 1 input data during the initial 18-24 months of the time series [Csiszar *et al*., 2014]. Those anomalies were gradually addressed by the VIIRS science team and their occurrence have dropped to virtually zero with the implementation of revised Level 1 data processing packages in 2015. Initial assessment of both VIIRS 375 m and 750 m was implemented over a few experimental sites indicating consistent fire detection and characterization performance. Additional data comparison analyses were implemented using near coincident Aqua/MODIS and TET-1 (German Aerospace Center) active fire data, which again showed consistent performance of the VIIRS active fire products across different observation conditions. Consequently, we consider the current data of good enough quality for use in fire management applications and scientific studies. However, users must be aware of the data quality limitations involving the archived data. NASA will be spearheading future data reprocessing efforts in order to generate a consistent time series for the VIIRS Level 1 and 2 data.

Q: *Are those few isolated fire pixels in the middle of the South Atlantic Ocean real*?
A: Those occurrences are typically associated with spurious fire detections due to the South Atlantic Magnetic Anomaly. The 375 m active fire algorithm contains a specific filter to flag those occurrences as low confidence detections. However, in some cases (average 2-3 pixels every night) the spurious signal generated in the input Level 1 data is confused for a regular fire pixel and therefore assigned a nominal confidence flag. Note that verified true positives can also be found over South Atlantic Ocean waters along the southeast coast of Brazil and the west coast of Africa where oilrigs normally operate.

## 7. References


Csiszar, I., Schroeder, W., Giglio, L., Ellicott, E., Vadrevu, K.,P., Justice, C.O., and Wind, B. (2014). Active fires from the Suomi NPP Visible Infrared Imaging Radiometer Suite: Product Status and first evaluation results. J*ournal of Geophysical Research: Atmospheres*, doi: 10.1002/2013JD020453.

Giglio, L., Descloitres, J., Justice, C.O., and Kaufman, Y.J. (2003). An enhanced contextual fire detection algorithm for MODIS. *Remote Sensing of Environment*, 87, 273-282.

Kaufman, Y.J., Justice, C.O., Flynn, L.P., Kendall, J.D., Prins, E.M., Giglio, L., Ward, D.E., Menzel, W.P., and Setzer, A.W. (1998). Potential global fire monitoring from EOS-MODIS. *Journal of Geophysical Research*, 103 (D24), 32,215-32,238.

Schroeder, W., Oliva, P., Giglio, L., and Csiszar, I. (2014). The new VIIRS 375 m active fire detection data product: Algorithm description and initial assessment. *Remote Sensing of Environment*, 143, 85-96.
Wolfe, R.E., Lin, G., Nishihama, M., Tewari, K.P., Tilton, J.C., and Isaacman, A.R. (2013). Suomi NPP VIIRS prelaunch and on-orbit geometric calibration and characterization. *Journal of Geophysical Research: Atmospheres*, 118, doi:10.1002/jgrd.50873.